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Improved Performance of DPFC Using Sliding Mode Controller Method

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Article Info	ABSTRACT
	Modern power systems demand the need of active power flow with the help of Power Electronics control devices is needed. In the family of Flexible AC Transmission devices (FACTS), Dynamic PFC (DPFC) offers the same controlling function as Unified PFC (UPFC), comprising the control of transmission angle, bus voltage and line impedance. A technical modification of UPFC is DPFC in which fluctuations of voltage at DC link is eliminated that enables the individual operation as series and parallel controllers. The concept of DFACTS is used in design of the series converter. The replacement of the high rating three phase series converter with the multiple low rating single phase converters results in cost reduction and increases reliability greatly. This DC Link is used to transfer the real power between two converters in UPFC such as in DPFC which eliminates the 3rd harmonic frequencies at transmission lines. D-FACTS converters are acting as insulation between high voltage phases acts as 1-ϕ floating with respect to ground. These results in lower cost for the DPFC system compared to the UPFC. This paper describes the comparison of PI and Sliding Mode Controllers which conclude that SMC is a better control strategy compared to PI.

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1.   INTRODUCTION

The increasing usage of electricity causes more demand in using the renewable energy sources make it compulsory to control a huge power that enables the power system for a quick switch between the renewable energy sources and the stand-by power generation [1]. This demands the availability of stand-by power whenever renewable energy is unable to supply the load. Therefore the need to control the power methods is increased [2]. The parameters used to control voltage value, transmission angle, line impedance are adjusted in order to enhance the power flow. The Power Flow Controlling Device (PFCD) is a device that tries to change system parameters to enhance the power flow performance. The combined FACTS components are the appropriate devices to enhance active power flow [2],[3]. The UPFC is the powerful PFCD, able to adjust line internal angle of the machine, bus voltage, and the parameters of transmission system. The major operation of the UPFC is executed with series converter by injecting the voltage, to control phase angle, magnitude, of the transmission line [3],[4]. DPFC emulates UPFC in independently adjusting the line impedance, control capability, internal angle between the bus voltage and induced EMF [5]. In DPFC there is absence of DC link which makes to interact converters back to back in UPFC [6].

Figure 1 shows the configuration of the DPFC in which each converter within the DPFC is operated independently due to one DC capacitor which provides the required DC voltage. Other than series and

parallel converters, DPFC needs a filter to bypass high frequency components connected in parallel to the Y-Δ transformer and service transmission line. The need of these extra components is explained later. There are two major advantages of DPFC compared to UPFC:
1. Isolation of low voltage and the series converter's low component rating causes low cost
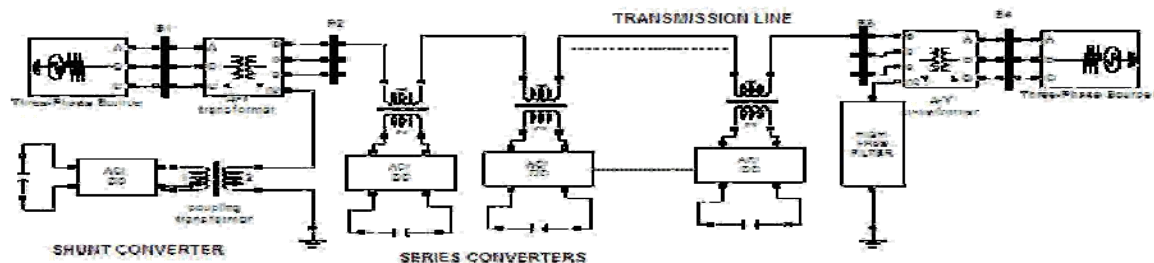2. The inability of the series converter in the system causes highly reliable

Figure 1. Complete Line Diagram of DPFC System

2. PRINCIPLE OF DPFC

In the Unified Controllers, there is common connection between the AC terminals of series and parallel controllers during exchange of real power. Non sinusoidal components were explained by power theory. In Fourier analysis, the non sinusoidal current and voltage is expressed by including several sinusoidal signals of different frequencies and amplitudes [7]. The real power that results due to non sinusoidal currents and voltages. The real power can be described in equation (1)

$$P = \sum_{i=1}^{\infty} V_i I_i \cos \emptyset_i \qquad (1)$$

where I_i =current , V_i = voltage , i^{th} = harmonic frequency ,
$\emptyset_i$ = phase angle between the harmonic currents and voltages.

From the above equation it is observed at different harmonic frequencies of active power are insulated from each other and the real power at other harmonic frequency is not affected by the voltage or current. The real power is independent at different frequencies; this controller without AC supply generating real power at one harmonic frequency to utilise the same power that other component frequency [7],[8]. Following the same approach in DPFC, active power can be absorbed by the parallel converter from source at supply frequency and inserted in to the system at other frequency component. This harmonic component of current flows through the power line. Based on the quantity of real power utilised by the system at the supply frequency, the voltage is generated by the DPFC series converters at the harmonic frequency thus absorbing the power from the line send by the other converter .Here a lossless converter is assumed, so that active power generated at fundamental component frequency and the power absorbed from the harmonic frequency are assumed as equal. The high-pass filter of the DPFC allows the passage of the fundamental components, blocking the harmonic frequency components, by that showing the harmonic components to have a return path. The harmonic current is circulated through high-pass filters, series and parallel converters and the ground. For the exchange of the real power in the DPFC the third harmonic frequency component is identified due to its unique character of the frequency 3rd harmonic components. In a 3-ɷ system, the fundamental and 3rd multiple component combined inject current into the grid." The zero-sequence harmonics is not allowed by Y– transformers, which are useful to mitigate reduce voltage level deficiency in power system. Therefore, there is no requirement of excess filter to rest of the network for mitigating the harmonic leakage.

2.1. Control principle ofDPFC

Figure 2 shows the three types of controllers that control the multiple converters; they are main control, series control and shunt control. The parameters of series and parallel control are maintained by themselves, they are also called as local controllers. At the system level the central control controls the DPFC functions. The function of these three controllers is given here.
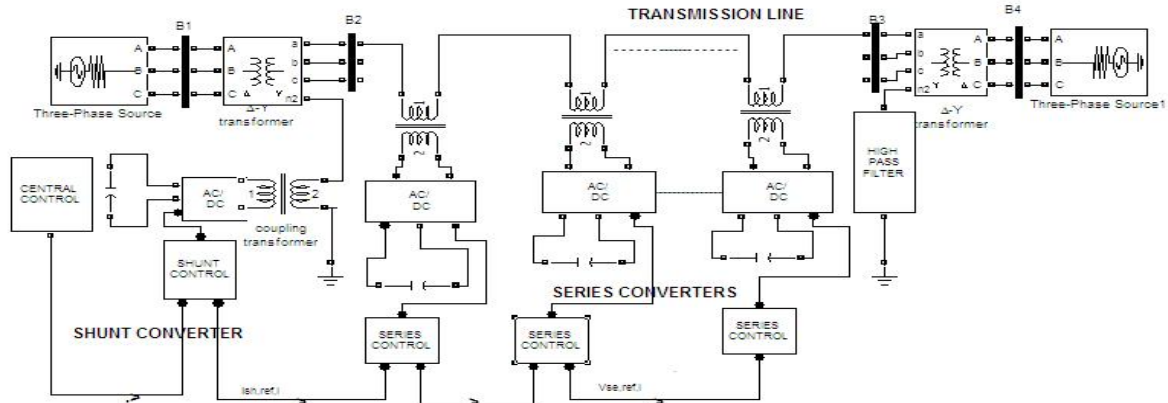
Figure 2. Block Diagram of DPFC with Controller

2.1.1. Main Control

The foremost function of the main control commonly known as central controller is to generate reference signals for controlled converters of the DPFC. These are generated at the system frequency. The central control gives reference signal of current and voltages for both the controllers in accordance with the system requirement [5]. At the system level, the central control is dependent on the functional operation of the DPFC; they are damp out power oscillations at low frequency, power-flow control and asymmetrical componentsbalancing.

2.1.2. Series Control

Series control is present in all the single phase converter circuits. The controller is to fix the capacitor voltage of converter with help of 3rd harmonic voltage or currents. It injects voltage at supply frequency approved by the main control [6]. In DPFC series converter control, the major control loop is the third harmonic frequency control. For DC voltage control phasor control principle is applied.

2.1.3. Shunt Control

It injects a fixed power which combination of fundamental and third harmonic component current into transmission line in order to transmit the real power for series converters is the main objective of shunt control. At the fundamental frequency of the 3rd harmonic current and bus voltage are locked. The motto of parallel converter is to exchange required Q vars to grid and also maintaining fixed DC capacitor voltage.

3.   CONTROLLER DESIGN

3.1. Controller design using PI

The transfer function of the PI controller is described as:

$$H(s) = K_P + KI_s \tag{2}$$

Proportional gain is derived using KP = 2.ξ.ωn.C which calculates the performance of the DC link voltage control. Similarly, the integral gain is derived using KI =Cωn2 that determines its settling time. The PI controller is to set the DC-link voltage as amplitude of the d axis current of the APF inverter to control the DC-link voltage for covering the inverter losses based on its reference value [9]. The difference of reference value of the APF current and measured value measured load current

3.2. Sliding Mode controller (SMC) of DC voltage

SMC strategy has been commonly applied for power converters problems, due to its operation characteristics such as stability, response fast and robustness during high variation in load [10]. The control action SMC utilizes SM theory as a jump function which is given by the equation (3)

$$s(y) = k.sign(y) \tag{3}$$

The Lyapunov function must be brought to zero; and to achieve this, it is sufficient that its derivative is not positive [10]. To minimize the chattering phenomenon due to the discontinuous nature of the controller, it is necessary to define a different function in neighborhood of the sliding surface with maximum and minimum limit value. If a point of the state trajectory falls within this interval, a smooth function can replace the discontinuous part of the control. Thus, the controller becomes [11].

$$un = \{kc/\varepsilon.(y) \; if \; |s(y)| < \varepsilon \neq 0$$
$$kc.(s(y)) \; if \; |s(y)| > \varepsilon \tag{4}$$

Where, kc represents the optimal gain value. In order to control the DC link voltage Vdc and to remove the chattering by using this SMC, the block diagram of the SMC strategy is given by Figure 3. According to Figure 3, the sliding surface ds(y)/dy = 0 is used to synthesis a command current I*[12],[13]. In this case I* is given by
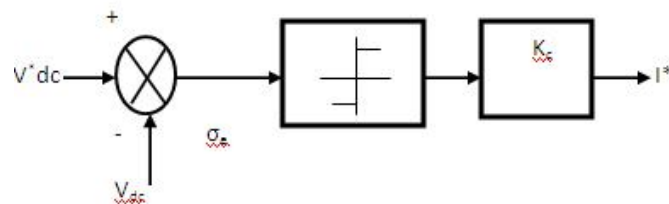
$$I^* = kc.s(\sigma c) \tag{5}$$

Figure 3. Block diagram of SMC Controller for voltage regulation

4.   SIMULATION RESULTS

To simulate the SMC or PI controlled DPFC, a model in Matlab/Simulink is developed. Simulation works are carried out to analyze the DPFC performance in a transmission system. A two bus power system is considered for simulation. Active Power flows between the two bus systems are obtained by allowing different phase between the two system. DPFC consists of 6- single phase series converters and shunt controller. The parallel converter is a 1-ɔ controller placed between neutral point of -Y transformer and solid ground, and on the other side of it is energised by constant DC source. Here a transmission system with a voltage of 380V and 50Hz is considered.

Table 1. System Parameters in Simulink

Parameter	Abbreviation	Value
Vs	Sending end voltage	220 V
Vr	Receiving end voltage	210 V
L	Inductance component in line	6 mH
θ	Angle between two end bus voltages	1º

Table 2. Measured Values of converter

| Symbol	Description	Value
Vsh,max	Maximum shunt voltage by shunt converter	50 V
Ish,max	Maximum shunt current by shunt converter	9 A
Ish,ref,	Shunt converter reference third harmonic current	3A
Vsh,dc	dc source supply	20V
Vse,max3	SereisconverteMaximum ac voltage at line side of	7 V
fsw	Sereis Converter Switching frequency for shunt and	6 kHz
Ise,max	Sereis Converter peak ac current at line terminal of	15 A
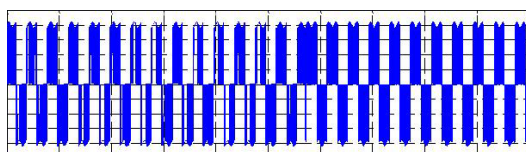
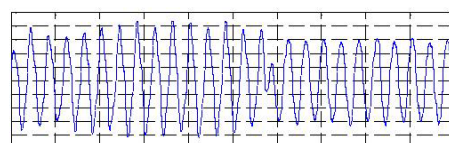

Figure 4. Series injected Voltage

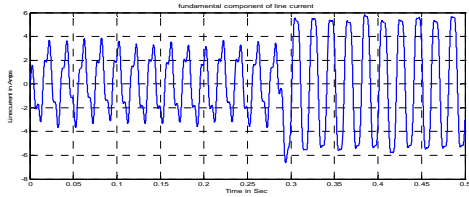Figure 5. fundamental component of injected voltage
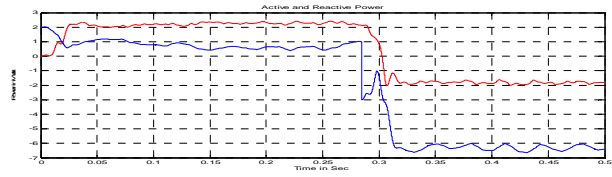
Figure 6 Fundamental Line Current
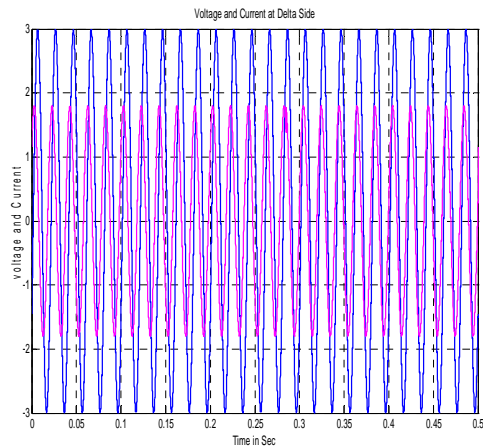

Figure 7. Active and Reactive Power
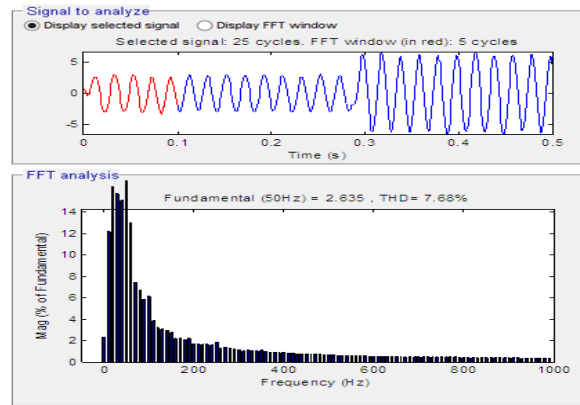

Figure 8. V and I Delta Side

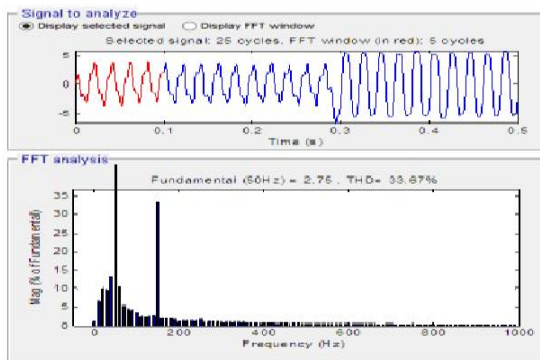Figure 9. THD Analysis at current at receiving end Side

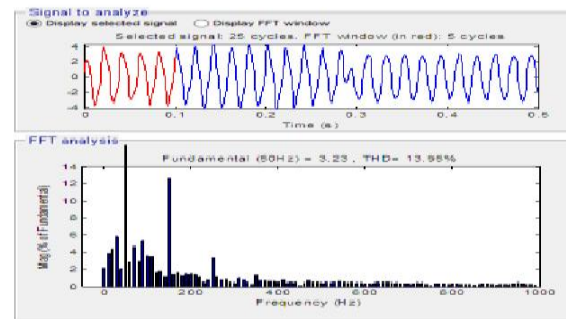Figure 10. THD Analysis of voltage at receiving end

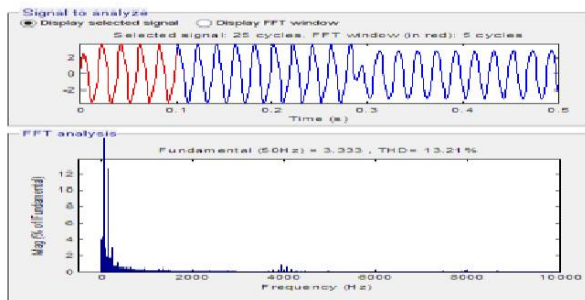Figure 11. THD analysis of Current at receiving end

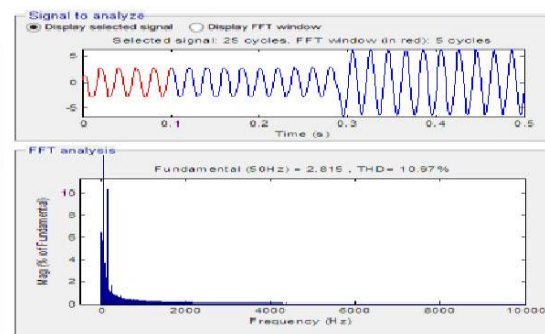Figure 12. THD analysis-Voltage

Figure 13. THD analysis- Current

Figure 14. THD analysis- I
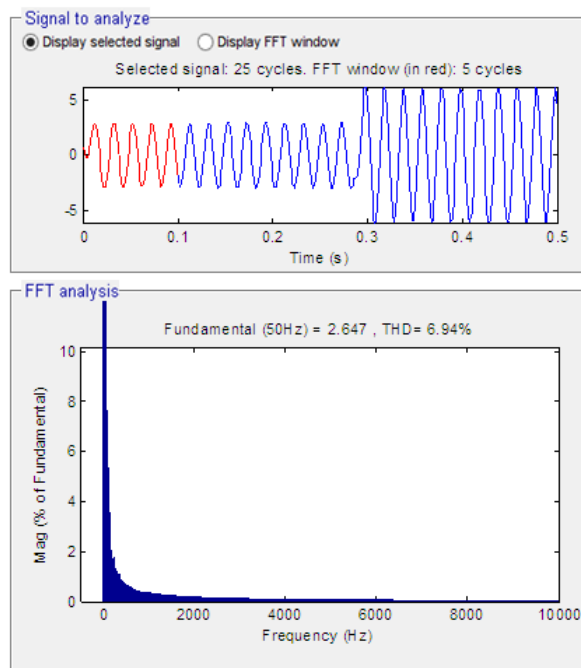
Table 3. Contains Performance Differences in Numerical with PI and SMC Method

	PI	SMC
Series inject voltage (1st and 3rd) component	78.9%	75%
Pundamental injected voltage	14%	13.2%
Line current	12.96%	10.9%
Current receiving end	7.68%	6.9%

5.   CONCLUSION

Two different control strategies for DPFC are presented in this paper. The first is based on proportional-integral controller (PI) and the second uses a sliding mode control (SMC). These controllers are used in order to regulate the voltage of the series controllerto improve dynamical performances. Several conditions have been performed in order to prove the THD of series injected voltage. The simulation is done using MATLAB/SIMULINK. The results obtained by simulation show that the SMC controller offers better performances than the PI. Table is given above.

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